FINAL REPORT

SERDP and ESTCP WORKSHOP ON TECHNOLOGY NEEDS FOR THE CHARACTERIZATION, MANAGEMENT, AND REMEDIATION OF MILITARY MUNITIONS IN UNDERWATER ENVIRONMENTS

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This report summarizes the results of a workshop sponsored by the Department of Defenses (DoD) Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) that sought to determine the research, development, test, and evaluation (RDT&E) needs to survey sites containing underwater munitions.

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ACRONYMS AND ABBREVIATIONS

AOI	Area of Interest
ASR	Archive Search Report
AUV	autonomous underwater vehicle
BIP	blown in place
BOSS	Buried Object Scanning Sonar
CA	chemical agent
CRAB	Coastal Research Amphibious Buggy
CSM	conceptual site model
CWM	chemical warfare material
DoD	Department of Defense
DVL	Doppler Velocity Log
EM	Electromagnetic Induction
EO	electro-optical
EOD	Explosive Ordnance Disposal
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Sites
GPS	Global Positioning System
INS	Inertial Navigation System
LARC	Lighter Amphibious Resupply Cargo
LBL	Long Baseline
LFBB	Low Frequency Broad-Band
MTA	Marine Towed Array
MMRP	Military Munitions Response Program
NOAA	National Oceanic and Atmospheric Administration
ONR	Office of Naval Research
PA	preliminary assessment
RDT&E	research, development, test, and evaluation
ROV	remotely operated vehicle
RTK	Real Time Kinematic

ACRONYMS AND ABBREVIATIONS (Continued)

SAS	Synthetic Aperture Sonar
SERDP	Strategic Environmental Research and Development Program
SIS	Sensor Insertion System
SNR	signal to noise ratio
SSAM	Small Synthetic Aperture Minehunter
UAV	Unmanned Aerial Vehicle
USACE	United States Army Corps of Engineers
USBL	Ultra-Short Baseline
UXO	unexploded ordnance

ACKNOWLEDGEMENTS

This report summarizes the results of a workshop sponsored by the Department of Defense's (DoD) Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) that sought to determine the research, development, test, and evaluation (RDT&E) needs to survey sites containing underwater munitions.

A steering committee composed of Dr. Kevin Williams, Mr. Andrew Schwartz, Mr. Christopher Penny, Dr. Larry Mayer, Mr. Robert Manning, Mr. Justin Manley, Dr. Sylvia Earle, Mr. John Dow, and Dr. Paul Carroll assisted SERDP and ESTCP in determining the scope and structure of the workshop.

Mr. Andrew Schwartz, Mr. Geoff Carton, and Mr. Bryan Harre wrote background papers and provided an opening presentation to communicate an overview of the Department of Defense (DoD) underwater munitions problem and requirements. Mr. Michael Tuley's presentation, provided by Dr. Anne Andrews, focused on lessons learned from terrestrial munitions response experience. Mr. Robert Manning presented the research program at the Office of Naval Research (ONR) and Mr. Justin Manley provided an overview of current underwater survey methods.

Dr. Larry Mayer, Dr. Shahriar Negahdaripour, Dr. Jim McDonald, Dr. Tom Curtin, and Dr. Richard Camilli presented technology-specific field perspectives as a basis for identifying and prioritizing needs.

Breakout groups discussing how technologies are applied throughout a typical underwater survey operation and how they may be applicable to the cleanup process for underwater munitions were led by Mr. Andrew Schwartz, Dr. Thomas Reed, Mr. Roger Young, Dr. Richard Camilli, Mr. Bryan Harre, and Mr. Thomas Bethge.

Breakout group discussions to identify key issues, barriers, and RDT&E needs were led by Dr. Larry Mayer, Ms. Barbara Sugiyama, Mr. Justin Manley, Mr. Mark Murphy, Dr. Kevin Williams, and Dr. Jim McDonald. Discussions for both breakout sessions were documented by rapporteurs, Mr. Jeffrey Fairbanks, Dr. Marvin Unger, and Ms. Katherine Kaye.

Within SERDP and ESTCP, Dr. Jeffrey Marqusee, Mr. Bradley Smith, and Dr. Anne Andrews, provided leadership in the conception and implementation of this workshop. Mr. Jeffrey Fairbanks, Ms. Veronica Rice, Ms. Katherine Kaye from HGL facilitated all developmental activities for the workshop.

Most importantly, we acknowledge the input of all workshop participants, whose input will guide a strategic plan to direct investments by SERDP and ESTCP in the area of detection and remediation of underwater munitions over the next 5 to 10 years. A list of participants appears in Appendix A.

EXECUTIVE SUMMARY

As a result of past military training and weapons testing activities, munitions are present at thousands of current and former Department of Defense (DoD) sites encompassing millions of acres. Many active and former military installations have ranges and training areas that include adjacent water environments such as ponds, lakes, rivers, estuaries, and coastal ocean areas. Modern geophysical surveying techniques can effectively be used to characterize sites potentially contaminated with munitions on dry land. However, the environment in underwater sites both restricts access to and may significantly impact the performance of established and emerging characterization technologies. Environmental concerns and safety considerations often restrict the use of common munitions recovery and demolition technologies underwater.

The Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) convened a workshop on July 31-August 1, 2007, in San Diego California, to define the future research needs in this area. The primary goal of the workshop was to allow government managers and investigators to explore ongoing work in related fields that may be applicable to underwater munitions sites, as well as to identify gaps in understanding that must be addressed by future research. SERDP and ESTCP, as DoD programs that promote the development and demonstration of innovative, cost-effective environmental technologies, must determine how their limited funds can best be invested to improve DoD's ability to address its cleanup requirements effectively in consideration of and in collaboration with past, present, and planned initiatives of other funding organizations and research programs.

The goals of the workshop were to establish guidance for DoD's future investments by identifying

- Gaps in capabilities that could be addressed through integration and demonstration of systems based on existing technologies, and

- Gaps in understanding that must be addressed by basic and applied research in phenomenology, sensor development, signal processing and supporting technologies.

In support of these objectives, participants were asked to provide an overview of the current state of the science and a critical review of current capabilities and the potential impact of funded research for detection and remediation of munitions in underwater environments.

The workshop identified a number of overarching issues and technology specific requirements that emerged in the final discussions as having the highest priority. These are listed below.

1. **Develop a Comprehensive Inventory of Munitions Response Sites in the Underwater Environment.** An assessment of the marine sites containing military munitions would assist DoD with understanding the types of sites that currently exist and would guide technology development for survey and remediation of these sites.

2. **Establish Test Beds for Evaluation of Sensor Technologies.** There is a need to develop one or more sites that can be used to determine the effectiveness of various sensor technologies for underwater surveys of military munitions. The test bed should include a range of munitions buried below the sediment surface and in a range of water depths.

3. **Evaluate Munitions Mobility in the Underwater Environment.** The transport of munitions over time should be investigated because it affects site management and cleanup decisions as well as establishing the required coordination of munitions response geophysical surveys with subsequent remediation activities.

4. **Characterize the Acoustic Response of Munitions and Typical Bottom Clutter.** Research is needed to develop a better understanding of the munitions detection capabilities of both well established and emerging sonar and acoustic systems. Work should include modeling studies, tank tests, controlled open water tests, and live site demonstrations.

5. **Combine Existing Sensor and Navigation Technologies.** Various sensor and navigation technologies have different strengths and weaknesses in the underwater environment. New combinations of sensor and navigation systems may provide enhanced capabilities for detection of munitions underwater.

6. **Investigate the Role of Chemical and Laser Line Scan Sensors.** Critical evaluation of existing chemical and laser line scan sensors could determine whether there is a role for these sensors in the underwater environment.

7. **Explore Munitions Indicators that can be Exploited for Wide Area Surveys.** On land, munitions related features such as aiming circles, munitions-related clutter, and impact craters are exploited to identify areas where munitions contamination is likely. Research should be conducted to determine whether analogous features exist and can be exploited in the underwater environment.

8. **Improve Detection of Smaller Munitions Items by Electromagnetic (EM) and Magnetic Systems.** Small munitions items are challenging to detect in both terrestrial and marine environments. Improvements in noise cancellation and development of platforms that operate very close to the bottom could improve detection of small items.

9. **Conduct Navigational Error Analysis.** The mission objective and choice of sensor will dictate the positioning requirements. An analysis of the error budgets of existing

and emerging navigation technologies should be conducted for a variety of environments and objectives.

10. **Improve Methods for Discrimination and Classification**. Processing techniques are required to enhance discrimination of munitions from clutter for any sensor that will be employed in the underwater environment. Discrimination and classification in terrestrial applications have focused on methods for estimating target parameters, such as size, shape, and orientation.

Each discussion session identified a number of technology-specific critical and high priority items for demonstration and research. Table 1 summarizes these needs.

Table 1
Critical and High Priority Research and Demonstration Needs

Research Needs	
Critical Priority	**High Priority**
Characterize Acoustic Responses of Munitions and Bottom Clutter	Determine if Munitions Indicators Exist to Support Wide Area Surveys
Improve Understanding of the Environment's Acoustic Response	Develop Innovative Approaches to Sonar and Other Acoustic Systems
Improve Methods for Discrimination and Classification	Improve Processing Time for Optical Sensors
Improve Methods for Noise Compensation	Improve Detection of Smaller Munitions Items
Study of Surf Zone Environment	Improve Navigation Error Analysis
	Develop Cooperative Cued Platforms
Demonstration Needs	
Critical Priority	**High Priority**
Demonstrate Existing Sensors	Demonstrate Existing Modeling Tools
Demonstrate Combined Sensors, Platforms, and Navigation Technologies	Identify Deep Water Demonstration Sites
Utilize Diverless Platforms	

The research and demonstration needs identified by the attendees for detection and remediation of munitions in the underwater environment will guide the SERDP and ESTCP strategic plan for investments in this area over the next 5 to 10 years.

1.0 INTRODUCTION

The Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) develop and transition innovative research and technology to help the Department of Defense (DoD) perform its mission in several environmental areas, including munitions response. Both programs have a substantial investment in the research and demonstration of technologies to characterize, survey, and remediate terrestrial sites contaminated with military munitions since, historically, the majority of munitions response projects have been on land. As the munitions response program begins to address the underwater environment, SERDP and ESTCP must determine how their limited funds can best be invested to improve DoD's ability to effectively address its cleanup requirements.

Within the Formerly Used Defense Sites (FUDS) program, The Army Corps of Engineers (USACE) has identified more than 400 sites totaling more than 10 million acres potentially containing munitions in underwater environments. The U.S. Navy and U.S. Marine Corps' munitions response program has identified an additional 20 offshore sites containing munitions. The inventory includes sites that date back to the 18th century and some that were used as recently as the 1990s. Current Navy policy is to include sites into the Navy's Munitions Response Program if those sites are covered by water no deeper than 120 feet deep.

Disposal of chemical warfare material (CWM) at sea in deep water environments was a common practice. Between 1919 and 1970, the U.S. Armed Forces disposed of approximately 29,000 tons of chemical agent (CA) at 16 locations in U.S. coastal waters. There are potential human health and environmental impacts of CWM, including injury or death from exposure to CWM, contamination of the marine environment and subsequent effects on the food chain, toxic concentrations of CA that washes ashore, and unintentional detonations of munitions containing CWM.

Little is known in detail about underwater sites, however, they encompass a wide variety of environments, including near-shore and off-shore ocean, swamps, rivers, and lakes. They also contain a variety of munitions types, which may include nearly any munitions in the historical inventory, including bombs, projectiles, mortars, grenades and rockets. Technologies to detect, characterize, and remediate areas contaminated with munitions need to be able to function in many underwater environments with varying bottom, current, salinity, visibility and clutter conditions. The development of technology specifically to address munitions response in the underwater environment is many years behind the technologies used on terrestrial sites. However, technologies developed for other underwater applications may be applicable or adaptable for munitions response.

The workshop described in this document was intended to define a path forward to guide DoD's future investments by identifying

- Gaps in capabilities that can be addressed through integration and demonstration of systems based on existing technologies, and

- Gaps in understanding that must be addressed by basic and applied research in phenomenology, sensor development, signal processing, and supporting technologies.

In support of this objective, participants were asked to provide an overview of the current state of the science and a critical review of current capabilities and the potential impact of funded research for detection and remediation of munitions in underwater environments.

Chapter 2 of this report summarizes the methods used during the workshop. Chapter 3 contains the major conclusions. Chapters 4 and 5 contain detailed summaries of the discussion sessions. The background papers provided to participants are included as appendices.

2.0 METHOD

More than 60 experts participated in the workshop (see Appendix A for a list of the attendees). The participants were invited with the goal of including knowledgeable experts representing a broad range of perspectives, including researchers, regulators, remedial project managers, and government agency representatives.

The workshop was structured to identify the most pressing needs in a focused manner, while ensuring that all participants were provided the opportunity and were encouraged to express their views. Prior to the workshop, participants were provided series of background papers addressing underwater munitions sites and environments, lessons learned from terrestrial munitions response experience, discussions of how underwater surveys are currently completed for other applications, and an introduction to potentially applicable technologies. The workshop opened with presentations summarizing the background papers.

Participants were divided into smaller working groups to address specific questions regarding the state of the science and to develop and prioritize key research and demonstration needs. Breakout sessions were first divided by survey objective, including wide area assessment, detailed surveys, and reacquisition and recovery. A second breakout session was organized based upon sensor technologies. The entire group participated in the final discussions and selection of the key issues and the critical and high-priority research and demonstration needs.

3.0 MAJOR FINDINGS

Throughout the workshop, several overarching themes emerged as priorities from the multiple discussion sessions. In addition, individual sessions identified specific topics that evolved to become consensus priorities in the final discussions. At the conclusion of the workshop, the following priorities became evident. Detailed summaries of the discussion sessions that led to these recommendations are provided in the following chapters.

3.1 DEVELOP A COMPREHENSIVE INVENTORY OF MUNITIONS RESPONSE SITES IN THE UNDERWATER ENVIRONMENT

Systematic surveys of underwater munitions sites have not been conducted, generally because the necessary technology has not been available. Hence, attributes of these sites have not been well characterized. There are lists of underwater munitions response sites that have been compiled by the services, but these lists contain very limited information. The Navy, for example, has just completed Preliminary Assessments of its sites and the COE has completed Archive Search Reports (ASR) for FUD sites. These documents summarize information known about the site from historical records, including the type(s) of munitions used. However, they typically contain little or no information on important underwater environmental conditions, such as bottom type, water depth, or current. Often, little is known about the quantity of munitions dispensed and whether they are proud, scoured in or deeply buried. Additionally, it is unknown to what extent they are expected to be mobile in the dynamic underwater environment.

An inventory is needed to catalog in greater detail the environmental conditions at the known underwater MR sites. Archival records rarely contain enough information to properly characterize a site. Tools available for this task include the National Oceanic and Atmospheric Administration (NOAA) maps and databases that can assist with determining the nature of the underwater environment. Other sources may include information available through the services that provide oversight at the various sites. In addition, a prioritized list of characterization and remediation activities would aid in prioritizing the development of technology capabilities.

3.2 ESTABLISH TEST BEDS FOR EVALUATION OF SENSOR TECHNOLOGIES

Several existing technologies are potentially applicable for detection of munitions in the underwater environment. Characterization technologies can be affected by bottom conditions, water clarity, depth, and potential mobility of the munitions over time, as well as the size and type of the munitions of interest and whether they are buried or proud. The establishment of a test beds for munitions response technologies would allow technology developers and government managers to assess and compare sensor and system performance over a range of conditions using a standard technical approach.

The group concluded that the initial test bed should be shallower than 120 ft, consistent with the criteria the Navy uses for inclusion of underwater sites into its munitions response program. A range of munitions should be placed proud and at various depths in the sediment. The site should be located in relatively calm conditions with low potential for item mobility

over time. The site should be easily accessible for mobilization of sensor systems to the site. The bottom environment of the site should be simple, flat, sand or hard mud, and with few obstructions. This would allow for assessment of various mapping and reacquisition technologies in benign conditions. This test bed is envisioned as a first step in testing various technologies under a variety of conditions. In the future, subsequent test areas could be created with increased complexity.

3.3 EVALUATE MUNITIONS MOBILITY IN THE UNDERWATER ENVIRONMENT

The evaluation of munitions mobility in the underwater environment can support risk assessment analyses and site management decisions. Models exist that can predict munitions movement under a range of average and extreme environmental conditions. Physical characteristics of the munitions and environmental conditions at a site can be used to feed models that determine whether munitions can be expected to be stationary of mobile. In addition, participants mentioned that models that were developed for other applications (i.e., sediment transport models) may be relevant to the underwater munitions problem.

Participants agreed that further investigation of mobility models is needed. Specifically, determining offshore movement of items to onshore environments supports human health risk assessment. This information can be used to support decisions regarding whether sites should be cleaned up or how frequently they should be monitored. It will also be useful to establish timelines required between detection surveys and reacquisition, where munitions are expected to be mobile.

3.4 CHARACTERIZE ACOUSTIC RESPONSE OF MUNITIONS AND BOTTOM CLUTTER

Munitions detection capabilities of well established and emerging sonar and other acoustic systems need to be researched and documented. Applying these technologies to support the munitions-response process requires a fundamental understanding of the acoustic response of munitions in underwater environments. The signatures of munitions vary depending upon 1) munitions type and size, 2) if it is fully intact, distorted or broken into munitions-related scrap, 3) if it is filled or empty, and 4) if it is buried, partially buried or proud. Creating a signature library could be a useful tool to record this information, which would be particularly useful for structural acoustic techniques. A progressive range of research, starting with modeling responses and basic tank tests with closely controlled variables, is suggested. This would be followed by controlled open water data collections and real site demonstrations that would provide further insight as increasing site variables are introduced.

3.5 COMBINE EXISTING SENSOR, PLATFORM, AND NAVIGATION TECHNOLOGIES

The suite of available technologies potentially applicable to detection and characterization of underwater munitions includes various combinations of sensor, platform and navigation/geolocation technologies. Sensors discussed during both breakout sessions included electromagnetic induction (EM), magnetic, optical, sonar/acoustic, chemical sensors, and laser

line scanning sensors. Platforms included autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), and towed arrays. Navigation and positioning technologies included long base line (LBL), ultrashort baseline (USBL), Doppler velocity log (DVL), real-time kinematic global positioning system (RTK-GPS), and inertial navigation technologies. Integrated systems may be used to determine the footprint of contamination during a wide area survey, to perform detailed surveys for individual item detection, or during the reacquisition process.

Participants agreed that an effort is needed to determine appropriate combinations of fully integrated sensors, platforms, and navigation/positioning technology for different applications. The strengths and weaknesses of existing sensor technology, along with the operational envelopes of vehicle technology and navigation systems, should be considered to determine the appropriate combination of sensors for different phases on munitions response. The production rate and coverage were discussed as key metrics for all phases of a survey, from wide area assessment to reacquisition and clearance. Also, whether common platforms could be used for fused sensor systems or whether multiple platforms were required for different phases was identified as a topic for further research.

3.6 INVESTIGATE THE ROLE OF LASER LINE SCANNERS AND CHEMICAL SENSORS

Both chemical sensors and laser line scanners were discussed as potentially applicable to underwater munitions, but there was not sufficient expertise present at the workshop to critically assess the potential role of either, nor the optimal research path.

A potentially valuable tool for detecting proud munitions or surface indicators of munitions use may be laser line sensors. These sensors can detect items to the centimeter scale, which lies between the resolution of fine scale still imagery and side-scan sonar. These sensors are expensive and bulky. Whether used as a stand alone system or as part of a fused system with other sensors, participants agreed laser line scanners should be further investigated.

Participants agreed that further assessment of available chemical sensors is warranted to determine if they can be useful for characterizing munitions contamination. Potential approaches discussed included:

- Investigating the use of chemical sensors for monitoring of deep water chemical disposal sites,
- Understanding munitions degradation underwater,
- Determining if there is a signature from either the metal casing or the explosive filler,
- Determining the proximity needed for detection of a signature, if it present,

- Investigating the use of chemical sensors as a tool for determining a footprint of contamination during the wide area assessment, and

- Determining appropriate platforms for these sensors.

3.7 EXPLORE MUNITIONS INDICATORS THAT CAN BE EXPLOITED FOR WIDE AREA SURVEYS

In the terrestrial environment, indicators of prior munitions use such as craters, aiming circles and other persistent surface features are detectable by lidar and high resolution photography. These indicators are useful for scanning large areas quickly to identify likely munitions sites that will require detailed investigation. It is not known if these features or analogous underwater 'indicators' may be present in areas of concentrated munitions that could be exploited as a detection tool.

It is unclear if munitions craters would remain in the underwater environment after impact and this topic should be further researched. Due to the complex nature and chemistry of underwater environments, indicators beyond surface scars could be present and should be investigated. For example, unique biological growth in an area of concentrated munitions due to the presence of explosives or degrading metal was postulated. Additional research is needed to determine if these or other indicators exist, and to identify sensors that would be most appropriate to detect them.

There are several existing and emerging sensors that have the ability to detect potential proud munitions or other features indicating munitions presence. These technologies have not been developed specifically for munitions detection and their performance in detecting proud and partially buried munitions items needs to be investigated through field demonstrations. Potentially applicable technologies include but are not limited to:

- Synthetic Aperture Sonar,
- Side-Scan Sonar,
- Multi-Beam Sonar, and
- Laser Line Scanners.

3.8 IMPROVE DETECTION OF SMALLER MUNITIONS ITEMS FOR ELECTROMAGETIC (EM) AND MAGNETIC SYSTEMS

Reliable detection of smaller munitions items has proven challenging for nearly all sensors and platforms. In terrestrial applications, it has been an on-going problem using existing EM and magnetic sensors. Similar difficulties have recently been observed in underwater detection testing at the Jackson Park site in Ostrich Bay, WA. Two contractors surveyed a constructed test site, known as a prove-out, that was seeded with a variety of munitions of interest. The magnetic sensors were deployed from a towed wing array and a multiple sensor platform was also suspended from a vessel with towing cable to prevent contact with the bottom. For the largest munitions (155 mm and larger), both systems detected the majority of the items (~60 – 80%). Smaller test objects were detected at lower percentages and the smallest objects

(40 mm rounds) were not detected at all. Additional work is needed to improve detection reliability, possibly including the development of platforms deployed closer to the bottom and the investigation of noise reduction techniques.

3.9 CONDUCT NAVIGATIONAL ERROR ANALYSIS

The overall level of certainty and confidence obtainable from a survey depends on the accuracy of the navigation and positioning of recorded data. The mission objective and choice of sensor dictate the positioning requirements. For wide are surveys, which simply seek to circumscribe contaminated areas, errors of tens of meters may be acceptable. However, for reacquisition of individual items for removal, absolute errors of <1m can be tolerated. Most stressing, for detailed surveys that seek to estimate target parameters using magnetometers or other sensors for individual object detection, relative measurement-to-measurement accuracy of a few cm is typically required. For a system with the objective of keeping a sensor a minimum distance off the bottom, both positioning and navigation errors of at most 10s of cm will be required, but for other platforms that do not closely follow the bottom, errors of a few meters can be tolerable.

In the terrestrial environment, positioning systems have been able to consistently obtain accuracy of a few centimeters, for applications with unobstructed views where GPS or robotic laser survey systems may be used. This accuracy is not currently feasible for underwater geophysical surveys.

There are various navigational technologies available for mapping in the underwater environment. One of the findings of the workshop was that there is a need to determine the location error budget of various systems that are applicable for different missions and conditions. These capabilities should be mapped to mission requirements, sensors and platform deployment concepts.

3.10 IMPROVE METHODS FOR DISCRIMINATION AND CLASSIFICATION

For terrestrial applications, numerous responses are recorded and must be investigated from non-munitions items for every munitions item detected. Processing techniques have been developed in recent years that work with existing sensors to discriminate munitions from clutter or geology. Discrimination in terrestrial applications has focused on methods for estimating target parameters, such as size, shape, and orientation from spatial signatures in magnetic and EM data. Low signal-to-noise ratios (SNR) and poor location accuracy limit the ability to analyze data to obtain meaningful parameters.

Many underwater sites with munitions contain large amounts of environmental clutter, debris, and obstacles, such as pilings, crab pots, anchors, coral, and trash. The ability to discriminate munitions from clutter using any sensor will be important. It is already known that work will be required to collect magnetic and EM data of sufficient quality to support advanced processing. Major challenges involve obtaining sufficient SNR and relative position accuracy at the cm level. Emerging sensors require similar considerations.

4.0 SUMMARY OF DISCUSSION SESSIONS: BY APPLICATION

Underwater surveys were discussed in three phases, modeled after the approach used for land-based munitions response: wide are assessment; detailed survey; and reacquisition and clearance. Attendees were divided into breakout sessions addressing these major topic areas. The sessions explored how technologies are applied throughout a typical underwater survey operation and how they may be applicable to the cleanup process for underwater munitions. This section captures the breakout session discussions in more detail.

4.1 WIDE AREA SURVEYS

The breakout session that was charged with discussing wide area surveys was asked to address the following questions as they related to the workshop objectives:

- How are large-scale surveys in marine environments currently accomplished? Discuss typical sensor types, platforms, and scale of survey areas in acreage. Are the survey platforms typically submerged, sea-level, or airborne?
- What are the primary factors that drive technology selection (i.e., technology availability, site conditions, targets of interest, survey objectives)? Are multiple technologies used based on the environment encountered (e.g., fresh water vs. salt water, deep vs. shallow)?
- Does a different group of operators work on the large scale surveys versus more localized surveys/identification? How does each group interact to ensure there is a common objective and that the data products support that objective?
- What are the key influencing factors that degrade data quality of currently used sensors/platforms?
- How can this process be applied to wide area underwater surveys for munitions?
- How can this process be improved?

These questions were intended as a starting point for the discussions; therefore, the discussion was not necessarily limited to these issues and, in some instances, these initial questions were modified to address issues the group found to be more relevant.

4.1.1 Recommended Underwater Wide Area Survey Process

A consistent approach to accurately delineate contaminated areas at underwater munitions sites is needed as marine sites move forward in the munitions response process. Given the primary focus of munitions response programs to date has been on land sites, it is an opportune time to develop a site delineation framework for marine sites. On land, several technologies applied high-altitude to ground-level platforms have been validated to conduct initial screenings of

large tracts of land. Some or all of them may be applicable for any given site. The objective of a wide area assessment is to produce high quality data, from multiple sources (if necessary), to provide a preponderance of evidence that identifies areas of concentrated munitions use and, just as importantly, areas that show no indications of munitions activities. This evidence could then be used to help guide decisions in the munitions response process. The participants agreed the terrestrial wide area approach can be adapted to address underwater munitions sites.

The participants recommended an initial environmental survey as an important information gathering step. An environmental survey was defined as a marine geophysical, geochemical and optical survey of the area with the objective of developing a comprehensive site model to characterize the survey area. Information to be collected includes, but is not limited to, the following: bathymetry maps, water column characteristics, bottom conditions such as roughness, presence of clutter, salinity, water clarity, and sub-bottom core information. Munitions detection is *not* the objective of this initial survey, although munitions or indicators may be fortuitously detected.

Based on the wealth of information gained from the site model, the most appropriate environmental survey technologies can be identified. The environmental survey may identify sub-areas within the site where specific sensors would be best suited. The site model can also be used to identify regions where munitions are not likely to be present such as sloped areas. Identifying regions on land where munitions are not likely to be present is one of the most difficult conclusions to support and the ability to provide evidence of that underwater is important.

Wide area survey technology selection on land is dependent upon information gathered from a site visit. Site characteristics such as terrain, vegetation, and geology are documented to guide the technology selection process. In addition, information gained from a conceptual site model (CSM) helps further guide technology selection. A CSM on land is a document created to record the current understanding of a site and is initially developed from historical documents. The participants observed marine environments inherently have more variables that can positively and negatively impact technology performance than land sites and these variables are not easily observed or measured during a site visit, particularly as water depth increases. Therefore, a more rigorous technology selection approach is recommended.

The participants agreed that existing environmental survey technologies are mature enough to be utilized for this purpose. In addition to their use in the environmental survey, they may also be appropriate for use in munitions detection. In either case the technology system should be fully tested and calibrated prior to use. Existing sensors to consider in an environmental survey include:

- Interferometric Side-Scan Sonar,
- Synthetic Aperture Sonar (SAS),
- Multi-Beam Sonar,
- Sub-Bottom Profilers augmented by Moving Vessel Profiler,
- Chemical Sensors,

- Optical Sensors, and
- Magnetic Sensors.

After a comprehensive site model is developed, a layered technology approach to wide area survey data collection remains applicable in the marine environment. The participants identified the wide area assessment phase as a search, classify and map survey. The objectives of this phase are to 1) detect concentrations of proud and buried munitions and 2) identify areas where there is no evidence of concentrated munitions.

Under ideal circumstances, there would be 100% data coverage for a survey if budget, survey area size, and schedule permit. The system deployment costs would generally be the survey cost driver, and not the survey time itself. As seen on land, if the budget is constrained and/or the survey area is large, statistically guided transects (widely spaced lines of data) are recommended. An added benefit of utilizing several existing sensors is their large swath widths could provide increased efficiency compared to land transect survey equipment. It is suggested that the currently used land-based statistical transect design software should be assessed for its applicability to marine munitions surveys employing not only the magnetometer and EM sensors for which it was designed, but also for alternative underwater sensors.

The participants agreed that existing technologies can be utilized in a search, classify, and map survey. Technologies developed for mine detection currently detect large objects, but some of them can potentially be modified for detection of proud and buried munitions. Sensors to consider for a search, classify and map survey include:

- Proud item detection sensors: SAS, Side-Scan Sonar, Multi-Beam Sonar

- Buried object detection sensor: Buried Object Scanning Sonar (BOSS)

- Applicable mine detection systems: Low Frequency Broad-Band (LFBB), Small Synthetic Aperture Minehunter (SSAM)

4.1.2 Exploit Detection of Proud Munitions and Other Bottom Features

The participants recognized the need to exploit munitions that can be detected on the bottom surface. Proud munitions would provide clear evidence that munitions activity occurred in the vicinity. The location of concentrated proud items could help guide more detailed future investigations. The participants recognized the need to research the potential for munitions mobility. For example, there is a need to determine if the location of the proud items would provide an accurate representation of where a target area and any associated buried concentrations of items are located. In addition, there is a need to further define water depth ranges and bottom and water surface conditions where mobility is expected. The presumption of the participants was that items deeper in the sediment are less mobile.

Additional underwater ‘indicators’ may be present in areas of concentrated munitions and could also prove to be a valuable detection tool. If present, bottom surface features, such as the presence of craters, could be exploited during a wide area survey. It is not known if munitions craters would remain after impact and this topic should be further investigated. Due to the complex nature and chemistry of underwater environments, the participants also speculated that indicators beyond surface scars could be present and should be researched. For example, unique biological growth in a area of concentrated munitions due to the presence of explosives or degrading metal was speculated. The participants agreed that additional research is needed to determine if indicators do exist, and which sensors would be most appropriate to detect them. These indicators could be analogous to the detection of munitions-related features on land such as aiming circles or craters that provide an additional layer of evidence to support site conclusions.

4.2 DETAILED SURVEYS AND AREAS OF INTEREST

In a typical munitions response investigation, following review of available historic information and identification of suspected Areas of Interest (AOIs), a more detailed survey may be conducted of the to establish the true boundaries of the AOIs and to detect individual munitions for removal. The breakout session that was charged with discussing detailed surveys of AOIs was asked to address the following questions as they related to the workshop objectives:

- How are the detailed surveys in marine environments currently accomplished? What are the typical sensor types, platforms, and scale of survey areas in acreage? Are the survey platforms typically submerged, surface, or airborne?

- What are the advantages of developing a concurrent, multi-sensor survey? Does it make sense to explore data fusion between the various, different sensor types (e.g., EM, magnetometers, acoustic, optical)?

- What are the primary criteria and standards that drive technology selection and design of the detailed survey? Are there effective regulatory and/or DoD guidance and protocols that might facilitate the detailed survey decision-making process?

- Would it be advantageous to conduct a detailed survey using multiple vehicles and platforms? What are the associated advantages and limitations? How might such combinations be effectively demonstrated?

- What are the current models used to discriminate bottom material, munitions, and clutter? How might these models be improved to provide better discriminatory capabilities?

- How can the detailed survey process be optimized? What survey tools have been successfully demonstrated, and, are such tools applicable at other detailed survey sites?

These questions were intended as a starting point for the discussions; therefore, the discussion was not necessarily limited to these questions and in some instances, these initial questions were modified to address issues the group found to be more relevant.

4.2.1 Defining a Marine AOI

AOIs can occupy any marine environment and include any munitions found in the historical inventory. It should be noted that marine technology for munitions detection and characterization is not as mature as terrestrial technologies and that marine AOIs are harder to define because records are fewer and less accurate and because there has been less subsequent interaction with humans. Finally, marine AOIs can change over time because of munitions migration.

The participants noted that AOIs can be identified from two perspectives:

- AOIs Identified from Data—These AOIs are identified from a number of information sources including historical records or sensor data (magnetometers, EM, sonar), and

- AOIs Identified from "Consequence"—These AOIs become evident from operational activities that involve intensive use, including recreational diving and boating, fishery, harbor activities, and dredging.

4.2.2 Technology Selection

In designing a detailed survey approach, participants identified a number of key, overarching drivers, including taking advantage of the latest technologies available, ensuring operator safety throughout the survey process, maximizing survey efficiency and flexibility, and obtaining and processing the collected field data.

While cost is expected to remain the main driver, there are other factors that will also drive the technology selection process. For example, the type of munitions (e.g., conventional versus chemical warhead, UXO versus DMM) and size might dictate the type(s) of tool(s) needed for identification. In addition, technology selection is likely to hinge on salient survey area features including water depth, munitions dispersal pattern, and density of clutter, along with environmental bottom conditions (e.g., coral, littoral, rock, sand, sea grass, visibility). These tools must then be configured with an appropriate underwater platform which may include towbodies, AUVs, ROVs, HOVs, and divers. Surveys in high energy surf zones present unique difficulties. Finally, participants stressed that the survey design (e.g., temporal survey, spatial survey, nested self consistent multi-phase surveys) will depend on these same conditions.

4.2.3 Survey Optimization

From a technology perspective, participants noted that there are a variety of innovations that could be used to advantage in creating a state-of-the-art marine detailed survey system for munitions response. Currently, there is no clear agreement on the best demonstrated available technology(s) for conducting surveys at underwater sites. Consequently, projects must evaluate a wide array of sensors and platforms for each site.

There are several civilian and government missions requiring undersea surveys. For example, NOAA conducts surveys to support its coastal charting mission using International Hydrographic Organization standards. Defense missions requiring undersea surveys include the Rapid Environmental Assessment (REA), Mine Countermeasures (MCM), and those directed by the US Navy Supervisor of Diving and Salvage (SUPSALV). Each of these programs has its own set of standards and requirements. Nonetheless, additional standardized approaches toward active detection and sampling, as well as for demonstrating marine munitions detection capabilities, should be developed. Standardization should result in identification of select technologies, sensors, and platforms that have been demonstrated to be effective in most applications.

A variety of new sensors are currently emerging including multi-aspect three-dimensional acoustic imaging, optical imaging, magnetic sensing, and the use of frequency-dependent acoustic responses (known as acoustic color). Complementing these tools, chemical sensors (e.g., mass spectrometers) deployable on light-weight platforms also continue to be developed for other applications. Sensor and platforms are never independent and the capability of the integrated system is a needed performance criteria metric to be assessed for the environment(s) being investigated.

Models that can predict target responses should be developed and extended. One class of needed models are considered generative; that is, modeling of targets and clutter without knowledge of the other, where identification is effected by selecting the model that best matches the unknown data. Other model types are discriminative; that is, the data from targets and clutter are simultaneously considered to determine the best boundary that separates targets from clutter. Additional research is needed in cases where existing models may break down. Examples of these include instances where the object is unduly close to the sensor so that the response is not represented by far-field assumptions. Another example is where the item of interest is constructed of multiple materials. Research is necessary to determine when more sophisticated approaches are required, what these approaches might entail, and which would be applicable to various situations.

In order to optimize a detailed survey, one needs to identify and address potential survey limitations. The size of munitions as well as the vastness and extreme water depths of some AOIs may limit the success of the survey. Additional survey limitations are encountered in inter-tidal areas and wetlands. Aside from location-specific issues, there are sensor technology considerations requiring attention if a successful detailed survey is expected, including sensor interference (i.e., crosstalk), visibility (for optical sensors), acoustic noise (sonar sensors), geology (magnetometers & EM), and challenges associated with ground truthing. Factors that

can degrade AOI survey data quality including sensor standoff distance, system motion and vibration, clutter, navigation precision, instrument noise and latency, and bottom topology.

The success of a project will be limited by clutter density, geologic noise and a difficult operating environment. Experience dictates a pragmatic approach in which the overall region is phenomenologically triaged to identify the best combination of sensors and platforms to achieve positive identification in specific subregions. A key strategy for marine detailed investigations will likely include adaptive sampling with feedback using optimal combinations of sensors and platforms. These hybrid systems, constructed based on specific munitions response missions, should be designed to be capable of effective data integration involving the multiple data collection tools.

A wide variety of sensors, tools, and platforms makes it hard to generalize the parameters of detailed surveys. The group recommended development of a matrix that provides the optimum operating conditions and features for the many various interrelated marine survey tools including type of munitions, platform, sensor, and environmental condition.

4.3 REACQUISITION AND CLEARANCE IN UNDERWATER SURVEYS

The final series of steps in the munitions response cleanup process includes reacquisition of anomalies identified in the detailed survey of AOIs, clearance of the items, and subsequent disposal. The breakout session that was charged with reacquisition and clearance was asked to address nine questions as they related to the workshop objectives:

- What are typical reacquisition objectives for underwater surveys?
- How is reacquisition of anomalies currently accomplished? Are different technologies used for mapping versus reacquisition?
- What is the typical size of an area to be searched and the required geolocation accuracy?
- What additional information is added by the reacquisition process? How is it used?
- What are typical reacquisition objectives for underwater surveys for munitions response applications?
- What are the environmental and technology limitations of performing a munitions response clearance?
- What regulations can limit clearance at certain sites?

- How can this process be applied to underwater munitions?

- How can this process be improved?

These questions were intended as a starting point for the discussions; therefore, the discussion was not necessarily limited to these nine questions, and in some instances, these initial questions were modified to address issues the group believed found to be more relevant.

4.3.1 Response Time Due to Mobility of Munitions

Once a Wide Area Survey has identified that an area potentially contains munitions and a detailed survey of the AOI has been completed, the anomalies are reacquired and removed or blown in place (BIP) by divers if the risk of moving them is unacceptable. Between the time the detailed survey is completed and the items are reacquired and cleared, the munitions may move due to storm events, water current, and/or wave action. In these circumstances, the timeline of the cleanup process must be adjusted to accommodate munitions mobility.

The group concluded that response time needed to be improved through all phases of a survey; particularly with respect to reacquisition and clearance. The process should be streamlined to ensure the same items can be located during the detailed survey and the reacquisition process. The group also discussed the possibility that the detailed survey team may be required to also perform the clearance operation due to the mobility of items. This would entail real time processing of the data collected in the detailed survey. The achievable production rates are different in shallow versus deep water environments.

4.3.2 Defining the Operational Accuracy of Positioning Systems

For terrestrial applications, positioning systems have been able to consistently obtain accuracy of a few centimeters, for applications with unobstructed satellite view for GPS or line-of-site for laser based robotic total stations. This accuracy is not currently feasible for underwater geophysical surveys due to water depths, environmental conditions, and technology limitations. Consequently, the search radius for reacquisition is larger than in terrestrial applications due to uncertainty in the positioning.

There are various sensor and navigational technologies available for mapping and reacquisition of munitions in the underwater environment. Each integrated sensor platform can detect items to a specified depth and location accuracy. One of the items discussed during this breakout session was the need to determine the location error of different systems at various depths. A preliminary matrix was developed by participants describing a number of systems and their corresponding error for mapping and/or reacquisition (see Table 2). This table needs to be expanded upon to fully address the different depths where munitions are found and the technologies capable of searching those depths.

Table 2
Navigational Accuracy of Various Systems

Depth	System	Accuracy	Comments
0-30 ft	SAIC Marine Towed Array (MTA) using a Real Time Kinematic (RTK) portable GPS	0.5m	Layback positioning, system used for mapping
10-120 ft	Ultra-Short Baseline (USBL)	1-3m	
10-120 ft	Long Baseline (LBL) and Doppler Velocity Log (DVL)	1-2 m	Navy Explosive Ordnance Disposal (EOD) uses this system for mapping only
600-10,000 ft	Inertial Navigation System (INS) and DVL aided AUV	5m	System used for mapping; requires sensor positioning
0-60 ft	Layback calculations	3m	
10-20,000 ft	LBL	1-5% of depth	General rule of thumb

4.3.3 Removal of Diver from Clearance Process

The use of divers is not cost effective or efficient for investigation of anomalies on the bottom and is potentially hazardous to the diver. Operating conditions for divers are limited, as dive times decrease with increasing depth. The U.S. Navy EOD divers use the circle, jackstay, and grid method, which involves a diver with a handheld sensor for target location and the "arm thrust" technique to locate and recover items. This technique involves thrusting an arm into the sediment up to the elbow and locating the object. The penetration depth in the sediment is typically 1-2 feet and the method can only be implemented when the sediment is soft. The hazards involved using this method are potential detonation of the item when moved and risks associated with other objects under the sediment. In addition, costs to support teams of divers are substantial.

Participants discussed substituting divers with other potential clearance technologies including small clam shells or dredges to clear items from the bottom and below the sediment. Additional work is required to improve the dredging process so items can be safely removed instead of left in place. Other technologies discussed included magnets to extract metal debris and robotic AUV systems with clamps that could be used to transport items to the surface or to an underwater holding area. In deep water environments, ROV technology was suggested as an alternative for clearance, should removal become necessary. Depth and bottom type will limit the type of technology used for clearance.

The overall sentiment from the group was that on-site decisions from program managers will be required for choosing specific technology at a site.

4.3.4 On-Site Treatment of Underwater Munitions

There are many hazards and costs associated with transporting munitions for off-site treatment and storage. In some cases, the risk to the diver of moving an item is unacceptable. Even in cases where an item can be moved, safety concerns arise with regard to consolidating, transporting and disposing recovered munitions, particularly UXO. Participants discussed

options for on-site treatment. Discussion focused on creation of a caisson or cofferdam at underwater munitions sites. These structures are built to create a dry work environment underwater.

Several on-site treatment options were discussed. For applicable sites, high order detonations in-place should be considered as an option for on-site treatment. Technologies should be developed to protect the environment from BIP operations. A bubble curtain engineered to mitigate the effects of underwater detonations on marine and aquatic life was discussed as a potential tool for use with detonation. Burn out technology could also be used to deflagrate the munitions, although residual environmental contamination from the remaining munitions constituents is a concern.

In addition, participants identified a number of regulations that can limit on-site treatment. These include, but are not limited to:

- Marine Mammal Act,
- Clean Water Act,
- Coastal Zone Management Act,
- National Historic Preservation Act,
- National Marine Fisheries Act, and
- Individual state water quality requirements.

5.0 SUMMARY OF DISCUSSION SESSIONS: BY TECHNOLOGY

During the second day of the workshop, participants were divided into breakout sessions by technology type, each with the same charge. Breakout groups discussed:

- Sensors/processing—sonar/acoustic
- Sensors/processing—EM/magnetic/optical/other sensor technologies
- Platforms and navigation technology

Participants were asked to integrate the key issues identified from the three application breakout sessions (wide area assessment, detailed survey of AOIs, and reacquisition and clearance) into discussions of research, development, test, and evaluation (RDT&E) needs to survey underwater munitions contaminated sites. Specifically, participants were asked to:

- Identify and prioritize critical research paths to enhance underwater munitions response production surveys.

- Identify and prioritize critical demonstrations that could be conducted in the near-term to achieve design, monitoring, or performance assessment goals.

Research and demonstration needs were classified as either critical or high priority, according to the definitions in Table 3.

Table 3
Criteria for Prioritizing RDT&E Needs

	Critical	High
Research	Research that could have a significant impact on detection and remediation of underwater munitions sites. (e.g., through design, implementation, and performance assessment of remedial technologies).	Research that is of high priority but may not be able to be initiated until critical research needs are addressed or may be more clearly defined after critical research needs are addressed
Demonstration	Field demonstrations or assessments that can impact our near-term ability to detect and remediate underwater munitions sites.	Field demonstrations or assessments that are of high priority but may not be able to be implemented until critical demonstrations or assessments are completed

The following sections describe the research and demonstration needs identified by the workshop participants within each breakout group. Discussions are generally brief and there is some overlap between the more basic research and development needs and the technology demonstration and validation needs, such as in the areas of fused sensor systems, characterization of the response of different items with various sensors, and improved noise compensation approaches.

5.1 SONAR/ACOUSTIC TECHNOLOGIES

5.1.1 Research Needs: Critical

5.1.1.1 Characterize Acoustic Response of Munitions and Bottom Clutter

Munitions detection capabilities of well established and emerging sonar and other acoustic systems need to be researched and documented. Characterizing the acoustic response of munitions in underwater environments is an essential first step. The signatures of munitions vary depending upon 1) munitions type and size, 2) if it is fully intact, distorted or broken into munitions-related scrap, 3) if it is filled or empty, and 4) if it is buried, partially buried or proud. Creating a signature library would be a useful tool to record this information, which would be particularly useful for structural acoustic techniques. A progressive range of research starting with modeling and basic tank tests with closely controlled variables was suggested. This would be followed by controlled open water data collections and real site demonstrations that would provide further insight as increasing site variables are introduced.

The presence of bottom clutter not related to munitions is a complicating factor for munitions detection. Determining the acoustic response of bottom clutter is necessary to assess if and how the clutter would interfere with the ability to detect munitions and distinguish them as the targets of interest. Potential interference includes masking the presence of munitions or mistakenly identifying bottom clutter as munitions if they are similar in size and shape. Research could be focused on bottom clutter that is typically found at munitions sites to help reduce false alarms and support higher probabilities of detection.

Information gained from acoustic response testing and modeling could be used to optimize these sensors, by supporting decisions such as frequency selection, resolution quality needed and range of transmission needed to detect munitions and associated scrap. Ultimately, site manager and regulator confidence in applying sonar and acoustic systems will be supported by these characterizations that validate their performance capabilities.

After these responses are further understood in a range of environments, associated technology data processing and classification techniques can be adapted for munitions detection and discrimination.

5.1.1.2 Improve Understanding of the Environment's Acoustic Response

Understanding acoustic response of the seafloor is needed. Knowledge gaps exist regarding how acoustic signals transmit through the seafloor. Characteristics of munitions response sites differ, so a variety of environments that reflect the most prevalent characteristics should initially be investigated. The results of this research in conjunction with the information gained from the acoustic response of munitions and bottom clutter will eventually help support technology optimization and selection by site.

5.1.2 Research Needs: High Priority

5.1.2.1 Explore Whether Munitions Indicators Exist to Support Wide Area Surveys

As discussed in the Wide Area Survey section, underwater 'indicators' may be present in areas of concentrated munitions which could prove to be a valuable initial screening tool. Bottom surface features, such as craters or proud munitions, could be identified during a wide area survey. It is unclear if munitions craters would remain after impact and this topic should be further researched. Due to the complex nature and chemistry of underwater environments, indicators beyond surface scars could be present and should be investigated. For example, unique biological growth in an area of concentrated munitions due to the presence of explosives or degrading metal was speculated. Additional research is needed to determine if indicators do exist, and identifying which sensors would be most appropriate to detect them.

5.1.2.2 Consider Innovative Approaches to Sonar and Other Acoustic Systems

Exploring and exploiting alternative sensor design configurations and sensor applications could provide gains in munitions detection. For example:

- Bi-static system designs could offer valuable additional information to support detection. The collective acoustic response to the environment and munitions themselves from additional transmit and/or receive components need to be explored.

- Increasing the frequency range of transducer technology is another potential development area. Existing and emerging technologies have been created for other applications and are not specific to munitions detection. Broadening their frequency range would likely illuminate smaller sized munitions items that may not be detected by existing systems.

- In addition to improved detection capabilities, alternative design configurations could also provide increased survey efficiency. Modifying systems to increase their swath widths would improve the survey production rates for transects and 100% coverage areas.

Existing concepts that have had minimal research to date could also be further investigated. For example, exploring the potential to transmit an electromagnetic pulse to extract an acoustic response from an item could yield munitions detection possibilities.

5.1.3 Demonstration Needs: Critical

5.1.3.1 Data Collections with Existing Sensors to Detect Proud Munitions Items

As discussed in the wide area survey section, detection of munitions on the seafloor would provide clear evidence that munitions activity occurred in the vicinity. The location of concentrated proud items can help guide site management decisions or plan future remedial

investigations. There are several existing and emerging sensors that have the ability to detect proud items. These technologies have not been developed specifically for munitions detection and their performance in detecting proud and partially buried munitions needs to be verified through field demonstrations. Research should investigate a range of munitions and their associated sizes to assess current capabilities. Applicable sonar technologies include but are not limited to:

- Synthetic Aperture Sonar,
- Side-Scan Sonar,
- Multi-Beam Sonar, and
- Buried Object Scanning Sonar.

5.1.4 Demonstration Needs: High Priority

No high priority demonstration needs were identified by the group for sonar/acoustic sensors.

5.2 ELECTROMAGNETIC, MAGNETIC AND OPTICAL TECHNOLOGIES

5.2.1 Research Needs: Critical

5.2.1.1 Improved Methods for Discrimination and Classification

For terrestrial applications, numerous responses are recorded and must be investigated from non-munitions items for every munitions item detected. Processing techniques have been developed in recent years that work with existing sensors under favorable conditions to discriminate munitions from clutter or geology. Discrimination in terrestrial applications has focused on methods for estimating target parameters, such as size, shape, and orientation from spatial signatures in magnetic and EM data. Low signal-to-noise and poor location accuracy limit the ability to analyze data to obtain meaningful parameters.

Many underwater sites with munitions contain large amounts of environmental clutter, debris, and obstacles, such as pilings, crab pots, anchors, coral, and trash. Discrimination using any sensor employed will be important. It is already known that it will be very challenging to collect magnetic and EM data of sufficient quality to support advanced processing to discriminate munitions from munitions-related clutter. Major challenges involve obtaining sufficient signal-to-noise ratio (SNR) and relative position accuracy at the cm level. Emerging sensors will face similar requirements.

Target discrimination in underwater sites could be based on feature-based prioritized lists of geophysical anomalies similar to what is done on land. Well-developed processing approaches for similar applications, such as mine detection, can be modified to utilize munitions-specific response information. The majority of participants agreed that real-time processing and classification of anomalies should be the ultimate goal because of the costs associated with detecting and reacquiring items in a dynamic underwater environment.

5.2.1.2 Enhanced Methods for Noise Compensation

Sensors and platforms do not function independently. Noise from the platforms can significantly affect the measured SNR and, in turn, the detection efficiencies and the false alarm rates. New research focusing on noise compensation methods to increase the SNR is a priority. Application of noise cancellation algorithms can mitigate the effects of the platform on the on-board sensor system. As new fused sensor systems with different platforms are considered for detection of munitions in the underwater environment, noise cancellation approaches should be improved or adapted.

5.2.2 Research Needs: High Priority

5.2.2.1 Demonstration of Optical Approaches

Optical imaging could be used to detect proud munitions or other visible indicators of munitions present. It is a mature technology that can be deployed on remotely operated vehicles (ROVs), with divers, tethered submersibles, and on AUVs, either alone or accompanying acoustic surveys. Visibility is the principal limitation for optical approaches. This technology has been used for mapping and detection of ship hulls and coral reefs.

Optical sensors have proven useful for 2D imaging of the underwater environment. The generation of 2D and 3D maps and video mosaicing have been demonstrated for other underwater applications. However, full 3D mapping and mosaicing are not currently achievable due to processing time of filters and signal processing algorithms. Optimizing these algorithms was identified by the group as a research topic. Other challenges involve navigational/positional accuracy and accurate registration of features between frames.

This technology, either as a stand alone system or fused with other sensors, is very promising for the underwater munitions problem. Participants suggested that demonstration of this capability for detection of proud munitions should be a priority.

5.2.2.2 Improved Detection of Smaller Munitions with EM and Magnetic Systems

Reliable detection of smaller munitions items has proven challenging. In terrestrial applications, it has been an on-going problem using existing EM and magnetic sensors. This has recently been demonstrated in underwater detection testing at the Jackson Park site in Ostrich Bay, WA. Two contractors surveyed a constructed test site, known as a prove-out, that was seeded with a variety of munitions of interest. The magnetic sensors were deployed from a towed wing array and a multiple sensor platform was also suspended from a vessel with towing cable to prevent contact with the bottom. For the largest items (155 mm and larger), both systems detected the majority of the items (~60-80%). Smaller test objects were detected at lower percentages and the smallest objects (40 mm rounds) were not detected at all. Additional work is needed to improve detection reliability, possibly including the development of platforms deployed closer to the bottom and the investigation of noise reduction techniques.

5.2.3 Demonstration Needs: Critical

5.2.3.1 Demonstrations for Electromagnetic Induction and Magnetic Sensors

Continued demonstration of both EM and magnetic sensors in the underwater environment was strongly supported. Potential investigations included fixing these sensors on an alternative platform, such as an Autonomous Underwater Vehicle (AUV), and recording data over known targets. Another application discussed was mounting sensors on very near-bottom platforms for data acquisition to minimize signal losses due to standoff distance between the sensor and the target. Additional discussion focused on demonstration of gradiometer configurations with existing magnetic sensors.

5.2.4 Demonstration Needs: High Priority

No high priority demonstration needs were identified by the group for EM, magnetic, optical, or other sensors.

5.3 PLATFORM AND NAVIGATION TECHNOLOGY

5.3.1 Research Needs: Critical

5.3.1.1 Study of Surf Zone Environment

The surf zone is a very difficult operating environment. If munitions response is required in this environment, a dedicated effort will be required for both detection and removal technologies. Platforms appropriate for the shallow surf zone demonstrations include Wave Riders, Crawlers, Towed Sleds, and Unmanned Aerial Vehicles (UAVs).

The example of electro-optic (EO) sensor applications in the surf zone was discussed in detail. Data from EO surveillance programs have been shown to contain dense clutter interferences from vegetation, fish, and man-made objects, and is further complicated by the water to land transition which has a significant impact on target SNR. Targets can be geometrically warped from the sea surface and by occlusion from sand and breaking waves. Land images typically have high SNR clutter with crisp edges while underwater images have lower SNR with blurred edges. Research is needed on automatic target recognition algorithms so that thresholds may be set high enough to reduce high false alarm rates from land clutter or low enough to detect and classify underwater targets.

5.3.2 Research Needs: High Priority

5.3.2.1 Cooperative Vehicles

Additional research is needed to develop vehicle systems that ultimately can be used to search large areas. A logistically manageable number of marine vehicles can work in coordination with each other to maximize both the search rate and search quality and, although both vehicles can operate independently, shared information can be used to improve their detection capability.

If underwater vehicles serve as survey platforms, they should be capable of fully autonomous navigation to the search area, including autonomous collision avoidance capability. Maximizing both the search rate and search quality will likely involve conditional sampling based on a triage approach that capitalizes on the speed, endurance, navigation and communication strengths. These cooperative vehicles would collectively investigate the area based on all available cues until a user-defined system performance level has been achieved. The output of the system is a map of the area showing the estimated positions and types of munitions, the confidence level of each estimate, and the probability of undetected munitions. At-sea field demonstrations should quantify the trade-offs between area search rate, coverage and composite map accuracies and confidence levels.

5.3.2.2 Navigational Error Analysis

The overall level of certainty and confidence obtainable from a survey depends on the accuracy of the navigation and positioning of recorded data. The mission objective and choice of sensor will dictate the positioning requirements. For wide are surveys, which simply seek to circumscribe contaminated areas, errors of tens of meters may be acceptable. However, for reacquisition of individual items for removal, errors of ~ 1m could be tolerated. Most stressing, for detailed surveys using magnetometers (or any other sensors) that seek to estimate target parameters for individual object detection, relative measurement-to-measurement accuracy of a few cm is typically required. For a towed system with the objective of keeping a sensor a minimum distance off the bottom, both positioning and navigation of at most 10s of cm will be required, but for other platforms that do not closely follow the bottom, errors of meters may be tolerable.

In the terrestrial environment, positioning systems have been able to obtain accuracy of a few centimeters consistently, for applications with unobstructed views where GPS or robotic laser survey systems may be used. This accuracy is not currently feasible for underwater geophysical surveys. There are various navigational technologies available for mapping in the underwater environment. One of the findings of the workshop was that there is a need to determine the location error of various systems that are applicable at various depths. These capabilities should be mapped to mission requirements, sensors and platform deployment concepts.

5.3.3 Demonstration Needs: Critical

5.3.3.1 Demonstration Sites

Sites need to be identified for demonstration of existing technologies. The breakout group identified two critical water depths to be considered: 1) 0 to 10 feet, and 2) 10 to 100 feet. In the 0 to 10 foot depths, local area demonstrations could test systems for detailed surveys as well as reacquisition and recovery projects. Navigation is not considered an issue (i.e., it can be GPS-based). The deeper 10 to 100 foot depth would support demonstrations for wide area assessments, detailed surveys, and reacquisition and recovery projects. Initially, targets should include 60mm and larger munitions, be sparsely populated, and include both buried and proud

items. Considered necessary for the effective demonstration of emerging underwater munitions response technology is a “simple” demonstration site; that is, marked by low clutter and a benign environment.

5.3.3.2 Diverless Platforms

Continued research efforts are recommended regarding the unique capabilities of diverless platform systems. Diverless systems with the ability to be accurately located and to remain in position, regardless of the wave conditions are needed. Diverless platforms can survive the harsh conditions of the nearshore. Diverless platform systems (e.g., Coastal Research Amphibious Buggy (CRAB), Lighter Amphibious Resupply Cargo (LARC), or Sensor Insertion System (SIS)) have allowed experiments to be conducted that would not otherwise be possible.

Such systems could be used to create large, precise arrays of bottom-mounted pressure sensors, current meters, and other oceanographic sensors that might provide new measures of ocean phenomena. Diverless platforms could provide detailed maps of the bottom, which are fundamental to most experiments. The use of diverless platforms for retrieval of munitions should also be explored.

5.3.4 Demonstration Needs: High Priority

No high priority demonstration needs were identified by the group for platforms and navigation technology.

6.0 CONCLUDING THOUGHTS

More than 400 underwater sites on former and current DoD installations may require remedial action because of past military training, exercises, and testing of weapons systems. There may be as many as 10 million acres of underwater sites contaminated with munitions. SERDP and ESTCP, as DoD programs that promote the development and demonstration of innovative, cost-effective environmental technologies, must determine how their limited funds can best be invested to improve DoD's ability to effectively address its cleanup requirements in consideration of and in collaboration with past, present, and planned initiatives of other funding organizations and research programs. This workshop was intended to define a path forward to develop and demonstrate new DoD underwater munitions survey technologies.

To provide needed capabilities, research, demonstration, and technology transfer objectives were identified and prioritized. Critical research needs included characterization and responses of various underwater environments, improved discrimination and classification methods, and noise compensation techniques for platforms. High priority research needs focused on improved detection capabilities of smaller items, improved processing time for optical sensors, munitions indicators for wide area assessment, development of innovative new sensors, improved navigational accuracy, and cooperative platform concepts. Critical demonstration needs included demonstration of existing sensors and existing diverless platforms. High priority demonstration needs focused on demonstration of existing modeling tools and identification of deep water demonstration sites.

The result of this workshop will guide a strategic plan to direct SERDP and ESTCP investments in detection and remediation of munitions in the underwater environment over the next 5 to 10 years.

Appendix A

Attendees

Shah Alam
U.S. Army Corps of Engineers,
Huntsville

John Allan
NAEVA Geophysics

Brian Almquist
Office of Naval Research

Anne Andrews
SERDP/ESTCP

Steven Arcone
U.S. Army, ERDC-CRREL

Jim Austreng
Cal/EPA-DTSC

Chet Bassani
SAIC

Charles Beauchamp
U.S. Navy, NUWC Division Newport

Thomas Bell
SAIC

Thomas Bethge
Oceaneering International, Inc.

Richard Camilli
Woods Hole Oceanographic Institution

Paul Carroll
U.S. Navy, NSWC-PC

Geoffrey Carton
ODASA (ESOH)

Harry Craig
U.S. EPA Region 10

Tom Curtin
Association for Unmanned Vehicles

Semme Dijkstra
University of New Hampshire

John Dow
U.S. Navy, NOSSA

Sylvia Earle
Deep Ocean Exploration and Research

Jeff Fairbanks
SERDP/ESTCP
Support Office

James Ferguson
International Submarine Engineering
Ltd.

Georges Fournier
DRDC Valcartier, Canada

Richard Funk
Tetra Tech EC, Inc.

Paul Greene
U.S. Army Corps of Engineers,
Baltimore

Robert Grieve
Bluefin Robotics Corporation

Roland Gritto
Multimax Inc.

Bryan Harre
U.S. Navy, NFESC

John Herbert
AMTI

Brian Houston
Naval Research Laboratory

Doug Hrvoic
Marine Magnetics

John Hyland
U.S. Navy, NSWC-PC

Ross Johnson
Geometrics, Inc.

Katherine Kaye
SERDP/ESTCP
Support Office

Eugene Lavely
BAE Systems AIT

Jeffrey Ledda
Oceaneering International, Inc.

Russ Light
University of Washington

Raymond Lim
U.S. Navy, NSWC-PC

Justin Manley
Battelle

Robert Manning
Office of Naval Research

Jeffrey Marqusee
SERDP/ESTCP

Philip Marston
Washington State University

Larry Mayer
University of New Hampshire

Jim McDonald
SAIC

John McIlrath
Tetra Tech EC, Inc.

Mark Murphy
U.S. Navy, NAVFAC NW

Shahriar Negahdaripour
University of Miami

John Noles
U.S. Navy, NAVFAC LANT

Michael Overfield
NOAA/ NMSP

Thomas Reed
Oceanic Imaging Consultants, Inc.

Veronica Rice
SERDP/ESTCP
Support Office

Daniel Rodriguez
US EPA, Region 2

Jason Rolfe
NOAA, Office of Response and
Restoration

Lynn Samuel
C & C Technologies, Inc.

Steven Schock
Florida Atlantic University

Andrew Schwartz
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Bradley Smith
SERDP/ ESTCP

Barbara Sugiyama
U.S. Navy, NFESC

Marvin Unger
SERDP/ ESTCP
Support Office

Bill Veith
U.S. Army Corps of Engineers, Huntsville

Tim Welp
U.S. Army Corps of Engineers, ERDC

William Wild
U.S. Navy, SPAWAR Systems Center

Kevin Williams
University of Washington

Richard Wold
hydroGEOPHYSICS, Inc.

Jody Wood-Putnam
U.S. Navy, NSWC-PC

Roger Young
U.S. Army Corps of Engineers, Huntsville

Matthew Zalesak
U.S. Navy, NAVEODTECHDIV

Appendix B

Agenda

SERDP & ESTCP

Underwater Unexploded Ordnance Workshop

Agenda

The Westgate Hotel
1055 Second Avenue
San Diego, CA 92101
619-238-1818

July 31- August 1, 2007

TUESDAY, JULY 31, 2007

0730-0830	Continental Breakfast (Savoy/Riviera Room)	
0830	Greetings and Objectives	Mr. Brad Smith Dr. Jeffrey Marqusee, SERDP/ESTCP
0845	Overview of Department of Defense Underwater UXO Problem and Requirements	Mr. Andrew Schwartz, U.S. Army Corps of Engineers, Huntsville
0930	Lessons from Terrestrial UXO Experience	Mr. Mike Tuley, Institute for Defense Analyses
1000	Research Program at the Office of Naval Research	Mr. Robert Manning, Office of Naval Research
1030	Break	
1045	Current Underwater Survey Methods	Mr. Justin Manley, Battelle, NOAA Office of Ocean Exploration

	Technology State of the Art Primers: Sensors, Platforms, & Navigation	
1115	Technology State of the Art: Sonar	Dr. Larry Mayer, University of New Hampshire
1130	Technology State of the Art: Optical/ Laser Line Scan	Dr. Shahriar Negahdaripour, University of Miami
1145	Technology State of the Art: Magnetics/Active Electromagnetic Techniques	Dr. Jim McDonald, SAIC
1200	Technology State of the Art: Platforms	Dr. Tom Curtin, AUVSI
1215	Technology State of the Art: Navigation	Dr. Richard Camilli, Woods Hole Oceanographic Institution
1230	Lunch *(provided to all attendees in the South Terrace)*	

	Breakout Session I: Concept of Operations in Underwater Surveys: The first breakout session will address how technologies are applied throughout a typical underwater survey operation and how they may be applicable to the cleanup process for underwater UXO.
1330	**Breakout I: Group 1- Wide Area Surveys** (Ambassador Room) **Breakout I: Group 2- Detailed Survey of Areas of Interest** (Coronet Room) **Breakout I: Group 3- Reacquisition and Clearance** (Embassy Room)
1500	Break
1520	**Breakout I** (Continued)
1700	Adjourn
1730-1900	Reception/Poster Session (Versailles Room)

WEDNESDAY, AUGUST 1, 2007

0730-0830 Continental Breakfast (Savoy/Riviera Room)

0830 **Groups Report Back from Breakout I**
(Riviera Room)

Breakout Session II: Technologies Used in Detection and Remediation of Underwater UXO: Breakout Session II will integrate the key issues identified from Breakout Session I into discussions of current technologies and the research, development, test, and evaluation needs to survey underwater UXO contaminated sites.

0915 **Breakout II: Group 1- Sensors/Processing (sonar/acoustic)**
(Ambassador Room)
Breakout II: Group 2- Sensors/Processing (EM/mag/optical/other sensor technologies)
(Coronet Room)
Breakout II: Group 3- Platforms/Navigation
(Embassy Room)

1030 Break

1045 **Breakout II** (Continued)

1200 Lunch *(provided to all attendees in the South Terrace)*

Group Discussion

1330 **Groups Report Back from Breakout II**
(Riviera Room)

1415 **Group Discussion:** The entire group will discuss- 1) Existing and emerging technologies that could be used or modified for use in the near term. 2) Knowledge gaps that will require a dedicated research effort.

1500 Break

1520 **Group Discussion** (Continued)

1700 Adjourn

Thursday, August 2 (0830-1200): CLOSED DOOR REPORT WRITING COMMITTEE CAPTURES OUTCOME

(Ambassador Room)